Ecological modernization of Caribbean agro-systems: From concept to design

Audrey Fanchone, Jean-Louis Diman, Gisèle Alexandre, Serge Valet, Harry Ozier-Lafontaine

CHAPTER NINE

Ecological Modernization of Caribbean Agrosystems: From Concept to Design

Audrey Fanchone, Jean-Louis Diman, Gisèle Alexandre, Serge Valet and Harry Ozier-Lafontaine

INTRODUCTION

Agriculture is now facing a new challenge, as it is not only expected to maximize production while reducing adverse impacts on the environment, but also ensure various ecosystem services (ES) and to diminish disservices (harmful effects). The Millennium Ecosystem Assessment (MEA), which pointed out the importance of proper ecosystem functioning for human well-being, was a turning point in the consideration of the services provided by agriculture. As a result, a transformation of agricultural systems from conventional agricultural systems is therefore expected. Since agrosystems are ecosystems controlled by humans, farming practices lie at the core of this transition of agriculture. Integrated systems are the main forms of farming systems observed all over the world, and in Latin America and the Caribbean (LAC), they represent a vast legacy of experiences in the history, tradition and culture of such countries.

Ecosystem services (ES): The multiple ways by which people benefit from ecosystems e.g.:

(i) Food: Ecosystems provide the conditions for growing food. Food comes principally from managed agro-ecosystems but marine and freshwater systems or forests also provide food for human consumption.

(ii) Raw materials: Ecosystems provide a great diversity of materials for construction and fuel including wood, biofuels and plant oils that are directly derived from wild and cultivated plant species.

(iii) Fresh water: Ecosystems play a vital role in the global hydrological cycle, as they regulate the flow and purification of water. Vegetation and forests influence the quantity of water available locally.

(iv) Medicinal resources: Ecosystems and biodiversity provide many plants used as traditional medicines as well as providing the raw materials for the pharmaceutical industry. All ecosystems are a potential source of medicinal resources.

More generally, in the Caribbean, multispecies systems whether mixed cropping systems, livestock farming systems or integrated ones, provide several ES. Using these systems as examples, this chapter examines the major driving forces that condition changes in farming practices. Agro-ecological engineering which relies on the ecological paradigm, is regarded as a suitable concept and approach to support this transformation. The chapter also proposes methods that might support the design of innovative agricultural systems, namely the step by step method and the *de novo* method. These methods are supported by concrete examples coming from several Caribbean or other tropical environments.

FROM THE 'GREEN REVOLUTION' TO THE DOUBLE GREEN REVOLUTION

After the Second World War, the shift from the concept of subsistence farming to the 'Green Revolution' represented a change in the prevailing agricultural paradigm, whereby the main objective assigned to agriculture was that of ensuring food security by securing an adequate market supply, a reasonable standard of living, and increasing farmers' incomes. During the 1980s, this production objective was largely achieved, and surpassed the requirements in Europe and many industrialized countries. This new standard involved the use of seeds of high-yielding varieties, primarily of wheat and rice, and the adoption of a modern package of agricultural tools and practices involving chemical fertilizers, tractors, pesticides, irrigation, mechanical threshers, electric and diesel pumps, among other things (Parayil 2003). This system, however, led to a decrease in farm numbers (rural exodus, loss of rural jobs), specialization and marginalization of territories, standardization of landscape, and deterioration of natural resources. The 'Green Revolution' also caused enormous environmental impacts, including soil degradation, water pollution and loss of biodiversity.

Agriculture is not only expected to produce food and fibre either for direct consumption or for industrial use, but also has to provide some other functions while at the same time minimizing adverse effects on the environment (Zhang et al. 2007). The new challenges faced by agriculture are to ensure various ES, to resolve apparent conflicts between them, and to diminish its disservices (Doré et al. 2011). The Millennium Ecosystem Assessment provided a new conceptual framework for analysing these multiple ES (MEA 2005). In new agrosystems, ES are not externalities, but are intentionally produced by stakeholders, who create such services by implementing practices (minimum tillage, crop association, organic fertilisation, integrated control of pests) which modify the production sequence. A new issue for researchers is therefore the evaluation of the cost of the production of such ES. In the International Assessment of Agricultural Science and Technology for

Development report (IAASTD 2008) it has been argued that the challenge to achieving this multi-objective agriculture not only requires continuing the development of disciplinary knowledge, but also more systemic approaches, and has recently officially called for a reorientation of agricultural science and technology towards more holistic approaches. New concepts such as 'agroecology' and 'ecological intensification' have been developed to support this transformation.

Vanloqueren and Baret (2009) have defined agroecological engineering as 'an umbrella concept for different agricultural practices and innovations such as biological control, cultivar mixtures, agroforestry systems, habitat management techniques (e.g. strip management or beetle banks around wheat fields), or natural systems agriculture, aiming at perennial food-grain-producing systems. Crop rotations, soil fertility improvement practices, mixed crop and livestock management and intercropping are also included. Some applications involve cutting edge technologies while others are old practices (e.g. traditional systems that provide significant insights to agroecology). For these authors, 'the scientific paradigm on which agroecological engineering relies is ecology (and holism)'. As such, the objective is the design of productive agricultural systems that require as few agrochemicals and energy inputs as possible, and instead rely on ecological interactions and synergisms between biological components to produce the mechanisms that will enable the systems to boost their own soil fertility, productivity and crop protection (Altieri 1995).

Some aspects of agroecological engineering may be related to biomimicry (Benyus 1997), as illustrated in Figure 9.1. Doré et al., (2011) noted that in natural ecosystems, as a result of the various animal and plant species, the final ecosystem is provided with a number of services, for instance pollination. In standard cropping systems, these interactions may lead to pest damage on crops, and so must be managed utilizing various control methods to limit yield loss. An increase in plant species diversity in systems mimicking natural ecosystems could allow natural enemies to control pests and generate ES (Doré et al. 2011). The concept of agroecological engineering, which sets out to improve the structure of the agricultural system and 'to make every part of the structure work well' (Liang 1998), differs from genetic engineering for example, which has as its primary objective the improvement of only a single element of the agroecosystem, for example (modifying existing plants or designing new plants).

Because agrosystems are ecosystems controlled by humans, farming practices are at the core of this transition of agriculture. According to Meynard et al. (2006) four major driving forces promote the transformation of farming practices. These are:

i. the recognition of the responsibility of agriculture in the deterioration of the environment;

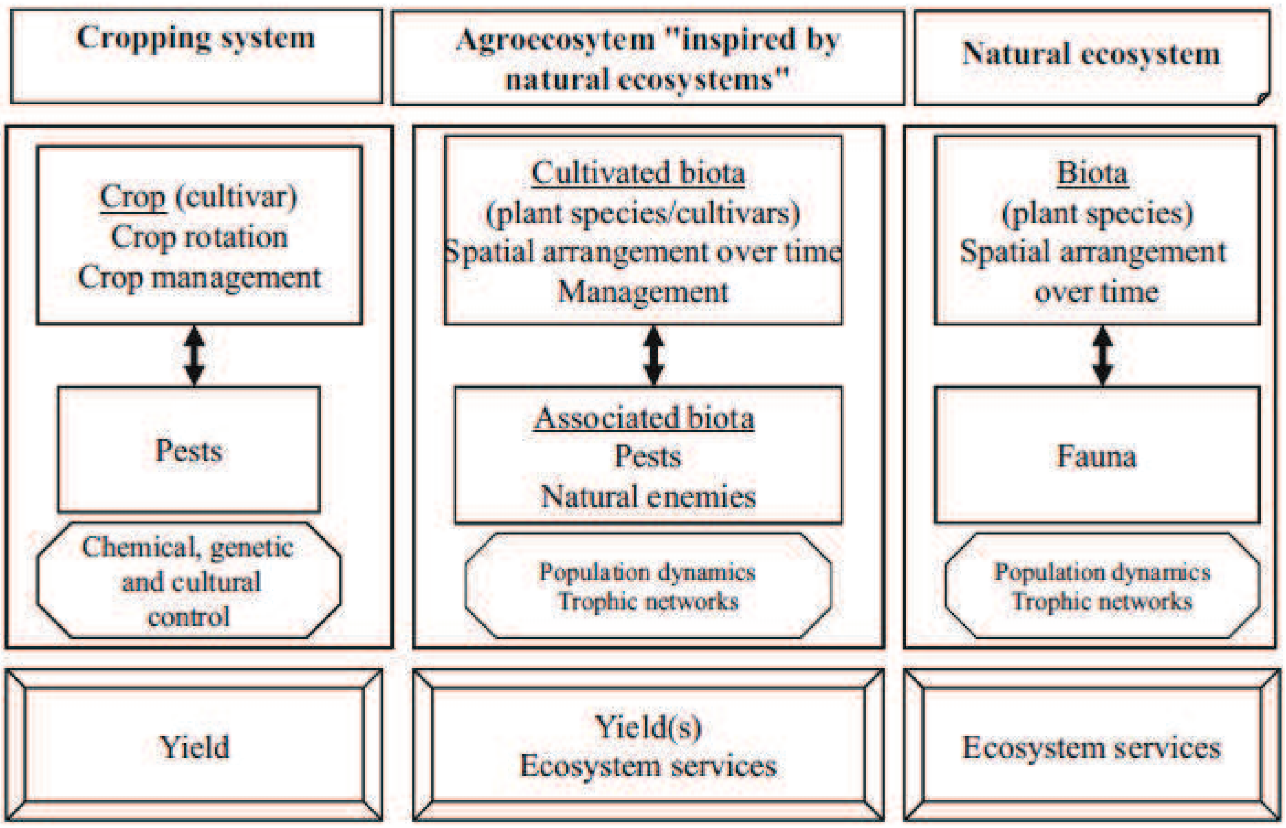
ii. the evolution of the demand for food and non-food products;

iii. the consideration of work and incomes of the farmers; and

iv. the evolution of the place of agriculture in the territories.

However, this transformation of agricultural practices presents some challenges. The first challenge is between the economy and the environment, because of the necessity to decrease inputs (e.g. fertilizers, phytosanitary products) and the absence of compensation for production losses or additional workload, with the second being between the individual logic of the farmers and that of the collective governance. This latter challenge is related to supply chains in the same territory, which compete directly or indirectly for the same raw materials such as fertile soils, flat lands, irrigated water and local breeds (Le Bail 2000).

Figure 9.1: A comparison of natural ecosystems, conventional cropping systems and agroecosystems inspired from natural ecosystems, with emphasis on crop protection.



Source: Doré et al. (2011)

Enhancing and integrating ES in Caribbean agricultural systems

In some parts of the world, integrated systems (IS) are the predominant forms of farming systems (Herrero et al. 2010). Nowadays, IS produce close to 50 percent of the world's cereals and most of the staples consumed by poor people: 41 percent of maize, 86 percent of rice, 66 percent of sorghum, and 74 percent of millet production (Herrero et al. 2009). They also generate the bulk of livestock products in the developing world: 75 percent of the milk and 60 percent of the meat, and employ many millions of people on farms, in formal and informal markets, in processing plants, and other parts of the value chain. Although there is a lack of available information in LAC, IS have an informal background of rich experiences in the history and tradition of these countries (González-García et al. 2012). In these countries, IS have persisted over time because as natural ecosystems, they appear to be well adapted to local constraints, after a long process of natural selection (Dawson and Fry 1998; Ewel 1999). This is even more the case for most of the small and large islands of the Caribbean where there are added constraints such as: the shortage of arable land and the high competition between agriculture and other uses such as urbanization and tourism. In these countries, the urgent need to increase outputs of each piece of agricultural land by producing food, feed, and other ES, tests the boundaries of conventional agriculture. The challenge in the Caribbean zone therefore becomes to promote IS which enable the provision of ES.

ECOSYSTEM SERVICES PROVIDED BY CARIBBEAN SYSTEMS

Multi-functionality and ecosystem services

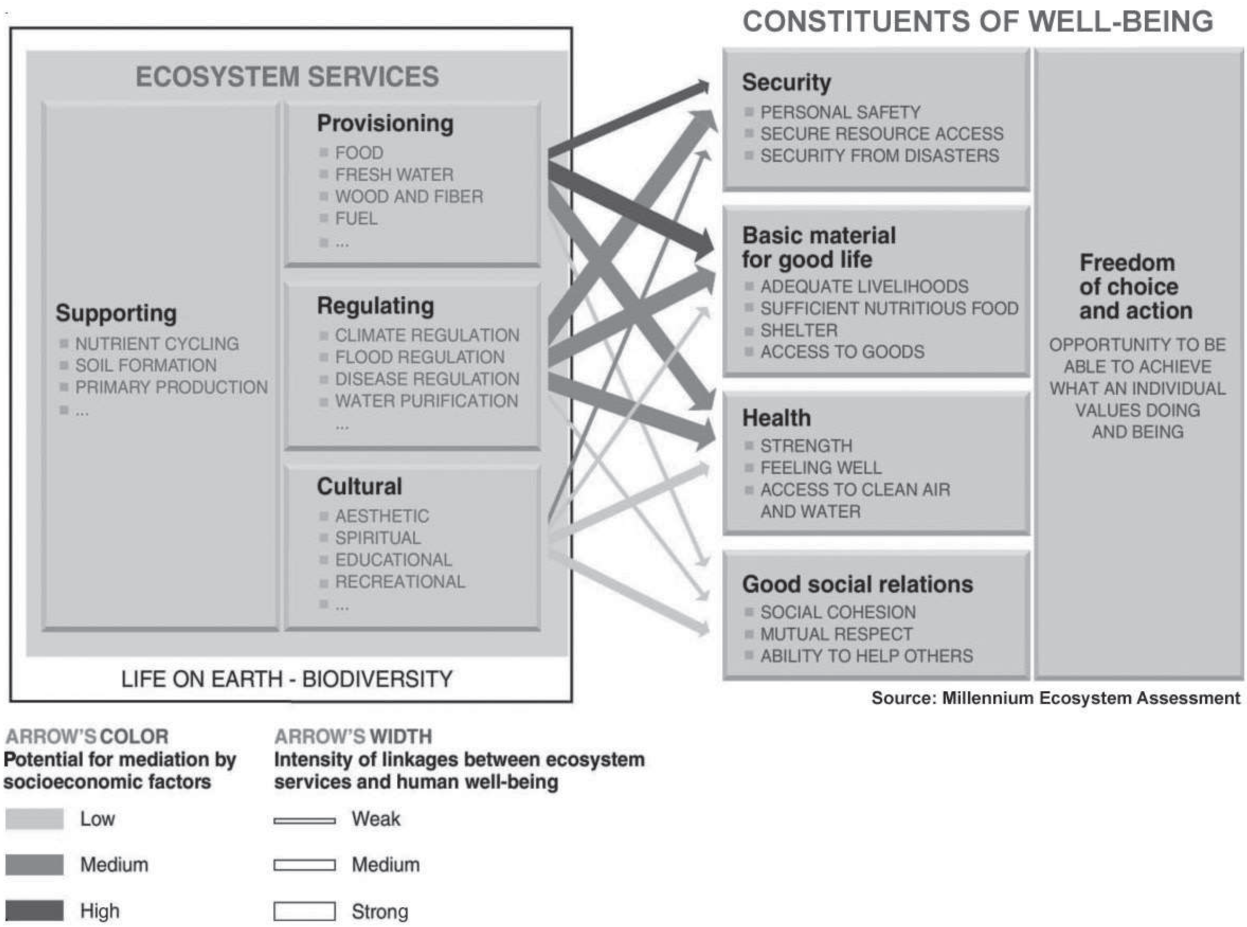
Agriculture fulfils three main functions, namely:

1. production (including economics aspects) – of food and non-food goods, and the provision of raw material for industry;
2. socio-cultural – to maintain the social fabric of rural areas, planning in territories and transmitting of a cultural heritage; and
3. environmental – biodiversity preservation, regulation of the environment, conservation and regulation of water quality, and to decrease energy consumption.

Despite an awareness of the multifunctional character of agriculture, this concept has not been embraced within the public policy context. According to MEA (2005), the acknowledgement of the importance of ecosystem functioning for human well-being, provided a turning point in the consideration of the services provided by agriculture.

The concept of ES not only encompasses the same functions as those expressed by multi-functionality, but also embodies the maintenance of the good functioning of the ecosystem. ES emphasize the human usage of natural processes through the supply of material goods, determine ecological regulation modes, and the role of the ecosystem to support both productive and non-productive activities.

Figure 9.2: The multi-scale framework of the Millennium Ecosystem Assessment



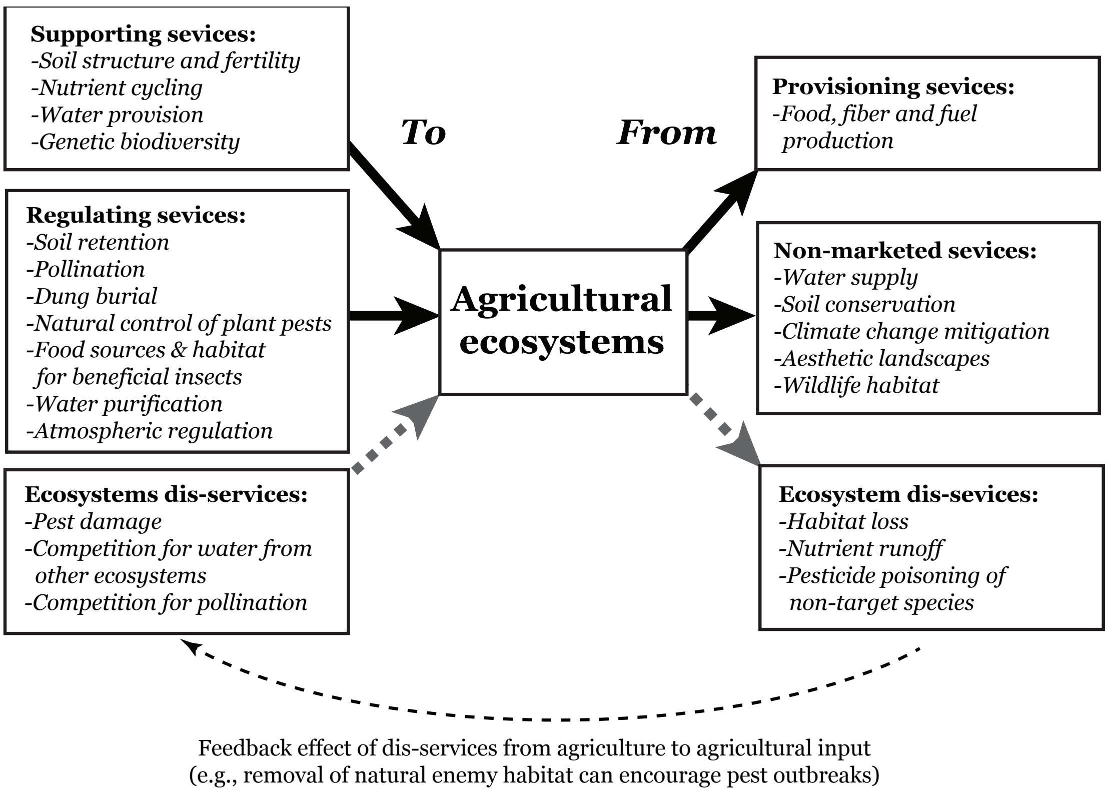
Source: MEA (2005)

THE MEA (2005): A CONCEPTUAL FRAMEWORK TO STUDY ES

The MEA defined four categories of ES; supporting, provisioning, regulating and cultural (Figure 9.2). The supporting services relate to services that are necessary for the production of all other ES. They differ from provisioning, regulating, and cultural services in that their impacts on people are often indirect or occur over a very long time, whereas changes in the other categories have relatively direct and short-term impacts on people. While the provisioning services relate to the products obtained from the ecosystem, the regulating services are the benefits obtained from the regulation of ecosystem processes. Finally, the cultural services relate to the non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences.

As the figure shows, many of the services listed within the MEA framework are highly interlinked and involve different aspects of the same biological processes. Moreover, MEA services only relate to the positive impacts of ecosystems on human well-being. The basic concept adopted by the MEA, is based on a multi-scale and multi-disciplinary approach that provides an integrated perspective by emphasizing the interdependence between socio-economic and environmental issues.

Figure 9.3: Classification of ecosystem services from the Millennium Ecosystem Assessment



Source: Zhang et al. (2007)

ES in agrosystems

The sustainability of agrosystems presupposes the preservation of their economic and ecological viability, i.e. the preservation of their productive capacity, as it relates to the maintenance of the good ecological functioning of the soils and the economical production of this system (market and societal value). Zhang et al. (2007) presented a conceptual framework for agrosystems and introduced the concept of disservices (Figure 9.3).

ES provided by multispecies systems

The following sections provide an overview of some of the ES provided by multispecies systems in tropical areas.

Mixed crop systems

In considering the provisioning of services, productivity per unit area can be increased when crops are combined, compared to single crops systems (Willey 1979; Jolliffe 1997), provided that the combination is suitable. Yield advantage occurs because growth resources such as light, water, and nutrients are more completely absorbed and converted to crop biomass by the intercrop over time and space. This is as a result of differences in the competitive ability for growth resources between the component crops, in characteristics such as rates of canopy development, final canopy size (width and height), photosynthetic adaptation of canopies to irradiance conditions, and rooting depth (Midmore 1993; Morris and Garrity 1993; Tsubo, Walker and Mukhala 2001). Biotic factors such as the presence of mycorrhizae, bacteria, fungi, termites and insects also play equally important roles (Derelle 2012). When tubers are used in combination with legumes/maize, the land equivalent ratios (LER) of the sweet potato and bean combination, ranges from 1.69 to 1.79, depending on density of beans. For a yam and maize/peanut combination, the LER ranges from 0.98 to 1.60, and was found to result in favourable yields/unit area, as well as yam tuber size (Cornet, 2005; Lyonga 1980; Odurukwe 1986). A tomato and cowpea combination produces a LER of 1.08 to 1.31 depending on their respective densities (Obedoni et al. 2005).

Soil protection/conservation services are also part of the regulating services. Cropping combinations and the hedges or trees associated with them, due to the high crop density, play a significant role in reducing soil and water erosion, thus contributing to the conservation or resilience of soils. An example of this can be found in West-Cameroon, where, as compared with mixed cropping systems, intensive monoculture was found to offer less soil protection against the 'splash' effect of raindrops that have high kinetic energy (Valet 1999). For andosols cultivated with maize monocrops on a 25 percent slope, such erosion can reach 122 T/ha/year (1996).

Pest and disease control represents yet another regulating service provided by multispecies systems. Five hypotheses are generally advanced to explain the ability of crop combinations to regulate plant pests:

1. The disruption hypothesis (push): one of the associated species disrupts the ability of the pathogen to attack the host plant by confusing it through the emission of volatile substances, visual effects, and a barrier effect (Khan et al. 1998).
2. The hypothesis of the trap plant (pull): one of the associated species attracts pathogens, keeping them out of reach of the more vulnerable crop and also attracts predators to the pests.
3. The natural enemies' hypothesis: based on the ability of mixed systems to favour greater diversity of predators and parasites.
4. The hypothesis of micro-environment modification: mixed cropping systems can either create more favourable conditions for the plant under attack, or less favourable conditions for the development of the parasite, or more favourable conditions for the development of its natural enemies.
5. Vertical and horizontal barrier effect – enabling plants to be concealed from insects, diluting the vector, modifying temperatures and the exposure that favours insects climbing up a stem.

One of the major roles of crop combinations is their ability to resist attack by multiple pests and diseases. An analysis performed by Risch (1983) on an assessment of pests and natural enemies in polyculture as against monoculture, showed that in 53 percent of cases, in the former, less serious attacks occurred than in the latter. More importantly, the percentage of natural enemies of mixed crops is greater than in monocultures (59 percent vs. 9 percent), yet in only 32 percent of the studies it was shown that there was no difference between monocultures and mixed cropping systems. The beneficial effect of mixed cropping in controlling disease and parasites was confirmed by other researchers (see for example Rämert, Lennartsson and Davies 2002; Root 1973; Szumigalski and Rene,2005; Vandermeer 1989). The beneficial effect is however not easy to demonstrate, as it is complex and unpredictable (Trenbath 1999). A cropping system with plant species used for different purposes can therefore assist in effectively addressing the issue of insect pests.

Livestock farming systems

Particularly under tropical conditions, a major challenge associated with livestock farming systems (LFS) has been a lack of recognition of the importance and benefits to be derived from the non-productive functions of animals, as well as the husbandry activities for the farmer/household and society (Lhoste et al. 1993). The LFS is not only concerned with the production of high-quality commodities, to meet the objective of food security, but also with the provision of multiple ecoservices as prescribed by MEA (2005). Animals and LFS are considered as highly multifunctional in tropical agroecosystems (Dedieu et al. 2011). With respect to the framework provided by Zhang et al. (2007), in the Caribbean, the first ES of LFS remains the provision of services (i.e. production of food, fibre, fuel). LFS also fulfil other categories of ES including: supporting services (soil structure and fertility, nutrient cycling, and genetic biodiversity), regulating services (soil retention, dung burial, atmospheric regulation), and non-marketable services (soil conservation, climate change mitigation, and wildlife habitat).

In most farming systems in the world, LFS are practiced in association with crops (Herrero et al. 2010). In such integrated systems, crop and livestock activities compete for the same scarce resources which include land, labour, capital and skills. Consequently, in general, the productivity of livestock in mixed systems (e.g. milk production/animal/day, growth and reproduction rates), is lower than in specialised systems, so that the provisioning ES can be considered somewhat reduced, leading to the conclusion that IS are less productive. However, while there may be lower productivity per unit land or animal in one enterprise, higher overall productivity is common. This has been demonstrated for example in the case of integrated dairy systems in Cuba that have been assessed to be as productive as intensive single systems and totally more sustainable (Funes-Monzote and Monzote 2001). From the IS perspective, livestock plays many vital roles in the households and economies of the developing world, including producing food and power, generating income, storing capital reserves, and enhancing social status (Alexandre et al. 2014). In addition, livestock can be used for weed control, production of manure for fertilizer (Boval, Bellon and Alexandre 2014) and also for fuel (Preston and Rodriguez 2014).

Crop–livestock integration is generally driven by increased population pressure, the main feature characterizing the Caribbean islands, which is often the main reason for farmers to intensify their farming systems. Livestock can affect the cycling of nutrients, opening alternative pathways, such as importation of nutrients from common land, and affect the speed and efficiency with which nutrients can be converted to plant-useable forms (Delve et al. 2001). Inclusion of livestock in mixed farming systems can provide an alternative use for crop residues. For example, if farmers need to plant a crop soon after harvesting a previous one, stubble incorporation may not be feasible, so that farmers may resort to burning it, resulting in increased carbon dioxide emissions. In contrast, livestock in IS can be used to remove and process stubble, potentially reducing the losses of carbon and nutrients. Blending crops and livestock has the potential to maintain ecosystem function and health and help prevent agricultural systems from becoming too ‘brittle’, by promoting greater biodiversity and an increased capacity to absorb shocks to the natural resource base, something which Holling (2001) defined as resilience.

From an ecological viewpoint, grasslands are ecosystems which exhibit a strong link between herbivores and floral diversity (Gliessman 2009) and when well-managed, can be a tool for ecological and regulating services, notably to maintain and restore biodiversity of the open landscape (Ma and Swinton 2011). Moreover, grasslands can potentially offset a significant proportion of global greenhouse gas (GHG) emissions. Appropriate management strategies, in the areas of stocking rate, grazing pressure and application of nitrogen fertilization would however be key (Boval et al. 2014). Animals contribute to improving the quality of the ground cover, important for soil erosion prevention and the watershed processes of infiltration and water retention (Gliessman et al. 2009). Thus, pastoral nomadism, a complex set of practices and knowledge, ensures the long-term maintenance of a sophisticated 'triangle of sustainability', which includes plants, animals and people.

Beyond the ecological services, natural resources and landscapes may provide numerous social, cultural, recreational, and aesthetic services which satisfy human need and well-being (Ma and Swinton 2011; Boval and Dixon 2012). As such, most traditional agroecosystems have remarkable characteristics which are regulated by strong cultural values and collective forms of social organization, including customary institutions for agro-ecological management, normative arrangements for resource access and benefit sharing, value systems and rituals (Altieri and Toledo 2011). Livestock production systems based on grasslands therefore have great potential for social equity, poverty alleviation, risk reduction and gender equality (Gliessman 2009). These services must be seriously considered as they are well supported by agro-ecological concepts. The development of local food chains, in addition to renewing the meaning of farm work and the social links between city and country, also has an impact on energy consumption (Mundler and Rumpus 2012). These are important in the context of the exploitation of grassland eco-economic factors and are properly taken into account in the agro-ecological concepts.

Examples of integrated systems in the Caribbean

From Creole garden to simplified multispecies systems

Multispecies cropping systems cover many modes of spatial distribution: on the surface, above and below the ground level, and time distribution, in relay with perennial or annual species (Valet and Ozier-Lafontaine 2014). The archetype of multispecies cropping systems in the Caribbean is the Creole garden that combines very different plants (e.g. grasses, shrubs and trees) in varying combinations, and in contrasting environments (i.e. lowlands and highlands). These systems are very close to agroforestry systems which incorporate trees and shrubs (Figure 9.4).

The principles of the Creole garden are very similar to those of agroforestry systems, as they involve the growing of annual or biennial agricultural crops along with forest species. The long-term effects of this system on soil fertility will however depend on the management practices adopted at establishment, as well as at subsequent re-establishment. Complementary, supplementary and competitive interactions exist between trees and crops, and higher crop yields have been obtained when some agricultural crops are inter-planted near leguminous trees such as *Faidherbia albida* (Acacia) (FAO 1994). Allelopathic interactions between trees and agricultural crops have also been investigated and such interactions have been reported (Susesh and Vinaya 1987). Many variations of this system are found in small family farms, involving between two and three species in the plots (Figure 9.5), which are not only chosen for human or animal consumption, but also for ES, namely in the form of the supply of nitrogen by legumes, and quick ground cover of creeping species for weed control.

According to Valet and Ozier-Lafontaine (2014), while the idea that ‘intercropping was only for peasant farming and has no place in modern agriculture’, has persisted for a long time among researchers and developers, it appears that in many areas of the world, traditional farmers developed or inherited complex farming systems in the form of poly-cultures that were well adapted to the local conditions. It has been further suggested (Valet and Ozier-Lafontaine 2014) that this has helped farmers to sustainably manage harsh environments and to meet their subsistence needs, without depending on mechanization, chemical fertilizers, pesticides or other technologies of modern agricultural science. These practices, which are generally more efficient than the high-intensity agricultural systems, highlight the ‘agroecological engineering’ developed over centuries by many peasants in tropical zones.

The Tosoly farm of Colombia

Preston (2009) has noted that farming systems should aim at maximizing plant biomass production from locally available diversified resources, processing of the biomass on the farm to provide food, feed and energy, and recycling of all waste materials. In addition, the generation of electricity can be a by-product of food/feed production instead of developing biofuels, which threaten food security (Suárez and Martín 2012). Biomass is fractioned into inedible cell wall materials that can be converted, through gasification into a source of fuel for the internal combustion engines driving electrical generators. The cell contents and related structures are used as human food or animal feed. It also offers opportunities for sequestration of carbon in the form of biochar, the solid residue remaining after gasification of the biomass, which in turn is used to enhance soil fertility and crop productivity.

On the Tosoly farm, located in a humid, tropical region of Colombia, the integrated food-feed-fuel model has been implemented by Preston and Rodriguez (2013). The farm is a medium-sized unit (7 ha), and in order to promote biodiversity, the crops (sugar cane, fruit and forage trees, and some forage plants) on the farm, are replicated in different areas. The livestock and fuel components are chosen for their capacity to utilize the crops and by-products produced on the farm. All crops must be at least dual-purpose, have good biomass productivity, as it relates to the efficient capture of solar energy (new energy revolution), and adequate chemical composition (in mixed diets).

The inclusion of livestock in the farming system is seen as a means of optimising the use of highly productive perennial crops such as sugar cane and multi-purpose trees. Sugar cane is easily separated into energy-rich juice, which can replace cereal grains in the feeding of pigs, as is done in Trinidad and Tobago, and Guadeloupe (Archimède et al. 2013), and residual bagasse, which can be used as one of the feedstocks for the gasifier. Forage trees are the natural feed resources for goats, which selectively consume the leaves, leaving the fibrous stems as another feedstock for gasification. Other farmyard animals are combined to maximize the use of feedstuffs, providing manure or draught power, and livestock products such as eggs, rabbit meat and honey. Any surplus commodities which remain after the family needs have been satisfied, are sold in the village market. Waste water from coffee pulping, family washing, and also all high moisture wastes from pigs and other animals are recycled through polyethylene biodigesters. Effluent from all biodigesters is combined and recycled to fertilise crops.

Fruit tree-crop-chicken farm of Martinique

Due to the wet climatic conditions found in Martinique throughout the year, fast weed growth is fast, resulting in the need for the implementation of permanent control measures in fruit tree crop systems, as this has a strong negative impact on yields. Weed control however generates high maintenance costs to fruit producers. Chemical weed control is the most common method used, but this is not a sustainable method due to issues related to water pollution and soil erosion (Hipps and Samuelson 1991; Duran-Zuazo and Rodriguez-Pleguezuelo 2008). Grazing animals which do not harm the cash crops therefore constitute a viable alternative. In Martinique for example, poultry (chickens and geese) were used in an orchard of guava trees and the feasibility and effectiveness of weed control were evaluated (Lavigne, Dumbardon-Martial and Lavigne 2012). It was found that although geese can be used to effectively control the herbaceous biomass, weed selection by the birds leads to a significant modification of the flora. The use of grass and perennial legumes in the orchard can also serve to enhance this cultivation system. The long-term effect of such an association however, remains to be assessed. Management of the stocking rate also plays a crucial role in such systems. In high stocking rate systems, over grazing can lead to deforestation and loss of associated biodiversity. This example shows how management practices can encompass both the provision of ecological services (weed management) and ecological disservices (loss of biodiversity).

The neo-tropical animal wildlife programme in Trinidad and Tobago

Added to the previous ES of production and regulation functions, this section underlines some other environmental and socio-economic services provided by livestock via the utilisation of an original case study. Tropical LFS have exhibited rich and high diversity not only for domesticated animals, but also for wildlife (species best adapted to their natural habitat). One is presented through the neo-tropical animal wildlife program implemented in the Caribbean (Garcia 2005). Around 30 important neo-tropical animal wildlife species are found in LAC. Twelve of these species are native to Trinidad and Tobago, where they are sold at higher prices than domestic animals. The neo-tropical animal wildlife programme fosters the high biodiversity of wildlife, building a whole concept to sustain a viable economic activity on the basis of AE principles developed at the food system level. According to Garcia (2005), the value of neo-tropical animal wildlife is varied, and can be broken down into an ecological role, economic importance, a nutritional function and socio-cultural significance. All of these features have a real impact on farmers' or hunters' income, gastronomy and agro-tourism in the country, something that is very difficult to assess.

The agroecological transition process in a family farm, San Juan, Cuba

The San Juan farm is one of the more than 100,000 farms distributed by the Cuban government in the recent years. It is located in Junco village in the Cienfuegos valley and is currently owned by the Rey-Novoa family, which has extensive experience in traditional agriculture. Funes-Monzote (2009) studied the agroecological transition process of this agroecosystem over a period of eight years (2004–2011), taking into account criteria of social equity, economic rationality and ecological sustainability. It is a traditional peasant farm, in which agroecological transition started in 2004, from land which was managed in a conventional agriculture mode and then abandoned for nearly a decade. A detailed characterization was performed which considered the attributes of sustainable agroecosystems in an annual cyclical process of assessment, design, management and evaluation, according to the methodologies proposed by Masera et al. (1999); Funes-Monzote (2009). The family was involved in the identification, selection and implementation of the indicators of sustainability.

The key lessons derived from the Rey-Novoa family experience with an innovative process of agroecological transition were (Rey-Novoa and Funes-Monzote 2013):

1. greater food self-sufficiency and traditional production;
2. promotion of local, drought-tolerant pasture in rotation or silvopastoral systems;
3. increased nutrient recycling, water, soil and forest conservation, and the biodiversity associated with native crops and animals;
4. account of natural conditions (male effect) in bovine reproduction;
5. genetic and species diversification on the farm via the integration of trees with crops and animals;
6. minimal dependence on external inputs for the basic infrastructure of housing, transportation, production, supply sources and reservoirs, irrigation of low power energy and water consumption.

The experience of the Rey-Novoa family farm shows that efforts to promote agriculture and knowledge processes in harmony with nature and society, must consist not only of actions to preserve and strengthen the productive logic of peasant families, but also a broad process of empowerment, capacity building and agricultural innovation at the local level, based on the participation of families with help from researchers, local institutions and rural organizations to redesign the agricultural land (Funes-Monzote 2013).

An agroecological transition model adopted in the context of the family farm is something that can be replicated within the framework of other agricultural systems found within the Caribbean in the quest for sustainability. As has shown, the process of agroecological transition helps to mitigate the degradation that exists in several agroecosystems. It is therefore critical that such studies should be continued. This will allow for the development of an agricultural model that is less dependent on oil, has a low environmental impact, is better suited to climate change, and can be characterised as a local and multifunctional agriculture.

Available tools and practical recommendations

In light of the foregoing, a number of tools are available for use, in addition to which, a number of practical recommendations can be made, which can be adopted to help in the management of these ecosystems.

Selection of cover crops for ES

At the National Institute for Agricultural Research (INRA) in Guadeloupe, an expert system, SIMSERV was developed to assist with the selection of cover crops (Ozier-Lafontaine et al. 2011).[1] This tool was created to optimise the selection of potential species to one or more services, while shortening the time of selection. This approach offers the advantage of capturing expert knowledge in an easily accessible and reusable database. For each cover crop, SIMSERV calculates the potential for it to provide a service in a given context, which is defined by the user who provides required information related to the: i) required service, ii) description of agroecological and socio-economic characteristics, iii) mode of establishment - in rotation or association, and iv) a cash crop.

The system matches the data defined for the particular context, with information from the database, which is then used to calculate the capacity for each cover crop to provide the service or not. The method of calculating is based on the aggregation of decisions in a "decision tree". Three profiles are given in the application: i) the administrator builds the decision tree; ii) the expert assigns values to the indicators to describe the cash crops and the cover crops; and iii) the user uses this information to describe his/her scenario, then chooses a context. Based on the analysis for each cover crop, the results, which are presented in tabular form, provide the user with an indication of the name and the qualitative assessment obtained for the selected service. Cover crops – 'very good', based on their capacity to provide the service, in response to the selected context.

Soil organic matter conservation

The soil organic matter (OM) is one of the essential components of agrosystems. Among its agro-environmental functions, OM helps maintain the structure and porosity of the soil (effect on water storage, its ventilation and the risk of erosion), stimulate biological activity, preserve biodiversity of the soil, provide nutrients to the crops (nitrogen, phosphorus, sulphur) and also helps to retain some micro pollutants (i.e. an effect on water quality). Changes in the OM content due to improper land use and farming practices, greatly affect all soil functions; the physical, chemical and biological quality. To address this, the MorGwanik© tool was developed.[2] It is based on the results obtained at the INRA French Antilles and Guiana Research Centre, with respect to the functioning of tropical soils, the fate of crop residues and the organic inputs (compost and agricultural reusable waste). It also takes into account the effect of the great diversity of soils and microclimates present in Guadeloupe on the OM content. MorGwanik© was designed to estimate the evolution of the OM content in agricultural soils of Guadeloupe according to some user-defined choices,

1. For further details on SIMSERV see: http://toolsforagroecology.antilles.inra.fr/simserv.
2. Further details on this tool can be found at: http://toolsforagroecology.antilles.inra.fr/morgwanik/index.php/morgwanik/.

such as location of the farm, useful crop rotation, type and rate of organic fertilizers used. It is intended for agricultural stakeholders such as farmers, technical advisors, policy makers, researchers, agronomists, and environmental professionals, and can also be easily adapted to systems found in the other Caribbean islands.

Animal feeding strategies

Both the quantity and quality of feeds are deciding factors not only for animal survival but more importantly to meet their nutrient needs for maintenance and production. Feeding and nutrition-related factors also impact upon, and often determine individual vulnerability to climatic constraints or potential diseases. Feeding practices should ideally match the available local resources as previously stated (Preston 2009). Many authors have recommended exploiting available feed and by-products instead of building a feeding system according to animal requirements (refer to the examples of sugar cane and cocoyam outlined in the section on the Tosoly farm). It is not a question of maximising the biological function of production, but rather optimising the feed resource partitioning at both the farm and territory levels, in the absence of competition between users.

The following section provides some recommendations in the area of feeding animals based on data gathered from Caribbean and Latin American experiences in the area of domestic animal (Table 9.1) and wildlife production (Table 9.2) suited for the region. Brown-Uddenberg et al. (2004) for example, reported that the agouti (*Dasyprocta leporina*) can eat any kind of vegetable matter, and in Trinidad, these animals, both in the wild and captivity, were reported to eat a wide variety of fruits from trees and shrubs (40 species), herbs and grasses (four species), garden crops (17 species) and livestock feeds. The peccary (*Tayassu tajacu*), a pig-like mammal, is known to be herbivorous and frugivorous in Brazil and Trinidad (Young et al. 2012) and is regarded as a pseudo-ruminant, thus indicating a potential for non-conventional farming.

Table 9.1: Foliage and non-conventional feeds offered to goats and pigs as examples of the high biodiversity of Latin America

Feed	Goat/sheep	Pig	Reference
Sweet potato (*Ipomoea batatas*)			
• foliage	x	X	2] and 4]
• tuber		X	2] and 4]
Cassava (*Manihot esculenta)*			
• foliage	x	X	2] and 4]
• tuber**		x	4]
Water spinach (*Ipomoea aquatica*)			
• foliage		X	2]
Mulberry (*Morus alba*)			
• foliage	x	X	1], 2] and 3]
Cocoyam (*Xanthosoma saggitifolium)*			
• foliage		X	2] and 4]
Gliricidia *(Gliricidia sepium)*			
• foliage	x		1], 3] and 4
Erythrina (*Erythrina glauca*)			
• foliage	x	X	3]
Banana (*Musa paradisiaca*)			
• foliage	x		3]
• stem	x		3] and 4]
• fruit***	x	x	4]
Sugar cane (*Sacharum officinalis*)			
• foliage	x		4]
• stick	x	X	4]
• juice		X	4]
• bagasse	x		3]

**after detoxification; ***goat - green; pig - green and ripe; x – study undertaken

Source: Iglesias et al. (2006)[1]; Rodriguez (2010)[2]; Alexandre et al. (2012)[3] and Archimède et al. (2014)[4]

Table 9.2: Resources consumed by wild mammals in Trinidad and Tobago

Feed	Agouti	Peccary	Reference*
Sweet potato (*Ipomoea batatas*)			
• foliage	x	X	1] and 2]
• tuber		X	2]
Cassava (*Manihot esculenta)*			
• foliage	x	X	1] and 4]
• tuber**		x	2] and 4]
Pumpkin			
• fruit	x	X	1], 2] and 4]
Water grass (*Commelina elegans*)			
• foliage	x		3]
Trichantera gigantea			
• foliage		X	4]
Leucaena leucocephala			
• foliage	x	X	3]
Banana (*Musa paradisiaca*)			
• fruit**	x	X	4]
Sugar cane (*Sacharum officinalis*)			
• foliage	x		1]

** Agouti – ripe fruit; Peccary – green

Source: Garcia et al., (2006)[1]; Nogueira-Fihlo (2010)[2]; Garcia et al. (2012)[3] and Young et al. (2012)[4]

THE CHALLENGE OF REDESIGNING FARMING SYSTEMS

Meynard et al. (2006) listed four major driving forces behind changes in farming practices. These are: the deterioration of the environment and the recognized responsibility of agriculture; the evolution of the demand of food and non-food products; the consideration of work and incomes of farmers in a globalized world; and the evolution of the place of agriculture in the territories. Because of these forces, some radical changes to cropping and livestock farming systems are emerging. The improvement of agricultural systems clearly calls for innovative measures to facilitate an improvement of the ES, the adaptation to climate change, the integration of territorial dynamics, and the design of agri-food systems.

The classic challenge remains between economic and environmental requirements. The other challenges are between the individual farmer's decisions and territorial dynamic, and between sectors of a same territory, associated with competition among different productions for territorial resources.

Resolving these challenges and reconciling contradictory demands require either the working out of new compromises, or the proposal of new solutions to resolve them, as against focussing on the somewhat unattainable desirable innovations or ideal farming systems. A systematic approach to innovation is required, which involves: identifying a range of solutions; leaving the decision-making to farmers and other stakeholders; helping them to build their own systems adapted to their specific realities; and in the process, compromising where necessary.

The pathways to innovative design

These encompass a consideration of the objectives and constraints of each actor in the innovative process, both at the farm level and at the country level. At farm level, in order to support farmers in the design of systems adapted to their situation, two major approaches can be distinguished: the 'de novo' design and the step-by-step design (Meynard et al. 2012). The 'de novo' design aims to design cropping or farming systems that break away from existing systems (very often model-based design), whereas, the step-by-step design incorporates the transition towards innovative systems by improving the existing systems step by step, in a progressive manner. This latter system is primarily based on a spiral of continuous improvement including diagnosis/development of possible systems/implementation/and new diagnosis.

At the country level, interactions of stakeholders around resource management need to be supported. Innovations relating to the co-ordination of farming systems at the country level can assist by taking into account the different interests of the various stakeholders which can be contradictory and often irreconcilable. Identification of action items for public authorities is at the core of the designing process since these constitute the means to facilitate the transition process. Public actions have to be taken carefully because: i) they sometimes strongly limit the capacity of farmers to adapt to the diversity of soils, climates and situations; ii) they are codified at the elementary agricultural technique level whereas environmental impacts often depend on interactions between several techniques; and iii) they are often felt to be constraints. Within this context, institutional innovation is required that will favour agronomic or agro-ecological innovation.

Scientists are then faced with a paradoxes since innovative design cannot be programmed (by definition) and yet it is essential if it is to fully feature in the programmes of research institutions/organisations and contribute to the shaping of scientific priorities, interdisciplinarity and partnership. The following section elaborates how this pathway was used to design systems adapted to the Caribbean region. Two examples are provided: the step-by-step design of citrus systems (Le Bellec et al. 2012) and the de novo design of banana farming systems (Blazy et al. 2010 and Archimède et al. 2012).

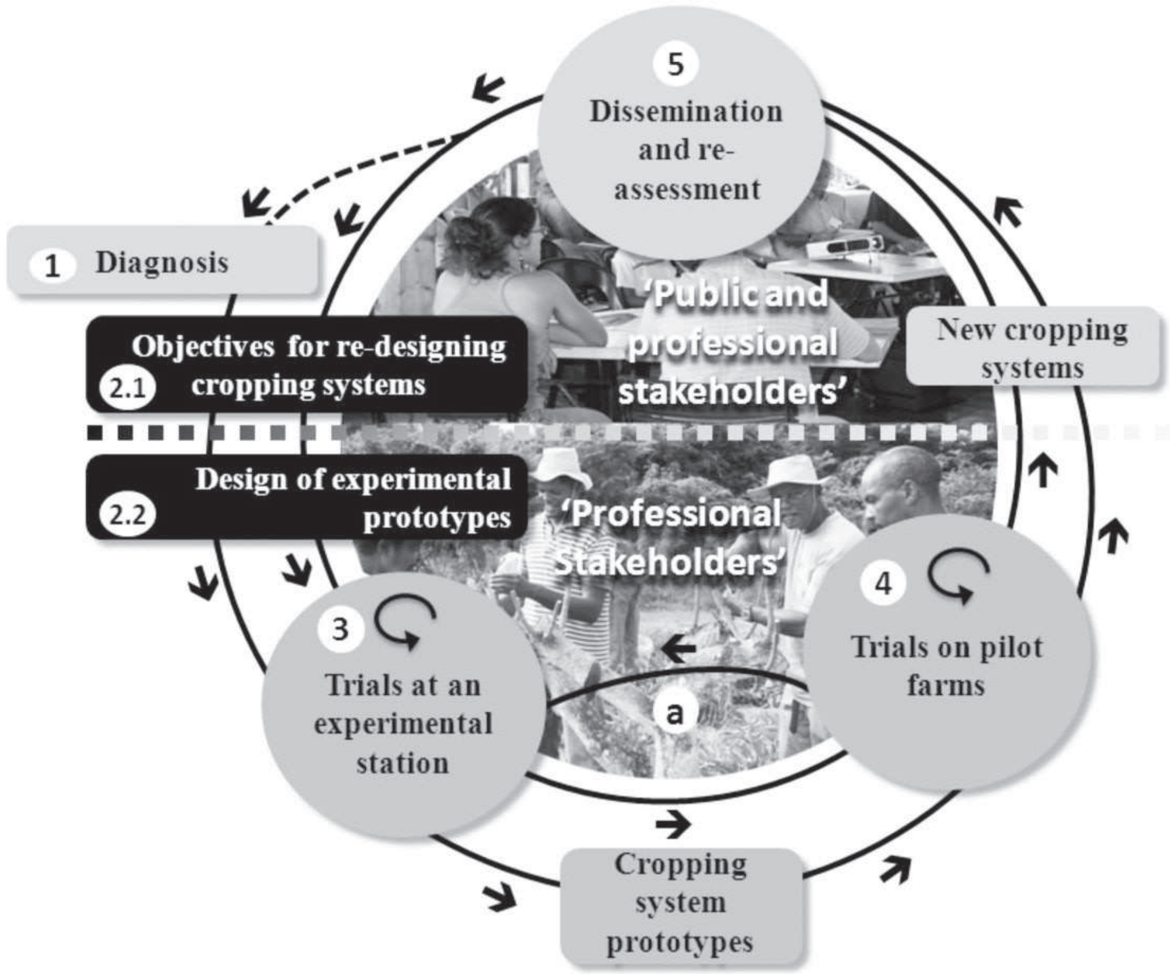
Examples of two design systems in the Caribbean

Step-by-step design of citrus systems

This design methodology has been used for citrus farmers in Guadeloupe as a mechanism to reduce herbicide load. Where changes were made in the field, the expectation was that there would be impacts felt within the whole farming system (local), in the agricultural sector (regional), and the pesticide industry (global). These represent some of the 'cascading effects' that are mostly unpredictable, but would nevertheless influence the general sustainability of the modified regional socio-economic and agricultural landscape (Kinzig et al. 2006). This demands a need for dynamic, non-linear, multi-stakeholder, and transdisciplinary approaches (Veldkamp et al. 2009) to sustainable development, in order to preserve the structure, identity, and functions of a 'socio-ecological system' (Walker et al. 2004).

With a view to redesigning an alternative citrus production systems adapted to the Guadeloupe particular context, Le Bellec et al. (2011) developed the DISC method (DISC: an acronym for re-Design and assessment of Innovative Sustainable Cropping Systems), which involves, a multi-scale, multi-stakeholder, participatory approach, and represents an improvement on the classical prototyping methods developed at field level. The DISC method involves four categories of stakeholders distributed into two distinct groups; professional stakeholders (farmers, researchers, and agricultural advisors), and public stakeholders (representatives of the State, regional institutions, civil organizations), and has been used to address citrus production in Guadeloupe (Figure 9.6), where local demand for citrus is covered mostly by imports. To satisfy this demand, producers had to increase production while reducing the use of pesticides, in accordance with French government objectives (Ecophyto 2008). This ruling was introduced at a time when citrus producers were still facing unresolved technical difficulties and were struggling to improve the quality of their products on the local market. The main concern in re-designing citrus cropping systems therefore was to develop lower-input cropping systems with improved economic and quality performances, in a move toward sustainable citrus production in Guadeloupe (Le Bellec et al. 2012).

Figure 9.6: DISC method application on the Guadeloupian citrus production



Note: 1) public stakeholders convey global orientations for local agricultural development through an agronomical diagnosis, and a participatory analysis,; 2.1 and 2.2) specific goals are set for citrus cropping systems redesigning (low-herbicide use); 3) at experimental station scale, five prototypes are tested and assessed with a specific grid; 4) two low-herbicide prototypes with satisfying global results are selected and transferred to citrus growers; the latter use decision-support indicators to monitor their practices while they integrate new techniques to their cropping systems. the set of ten indicators characterizes a degree of sustainability of the cropping system; once innovative cropping systems are running, their number on the local area leads to the validations of global goals; at local area scale, three indicators will assess the realization of the goals; 5) through multi stakeholder consultation and, if need be, through a new agronomical diagnosis, new goals are set for the pursuance of the innovative process

Source: Le Bellec et al. (2012)

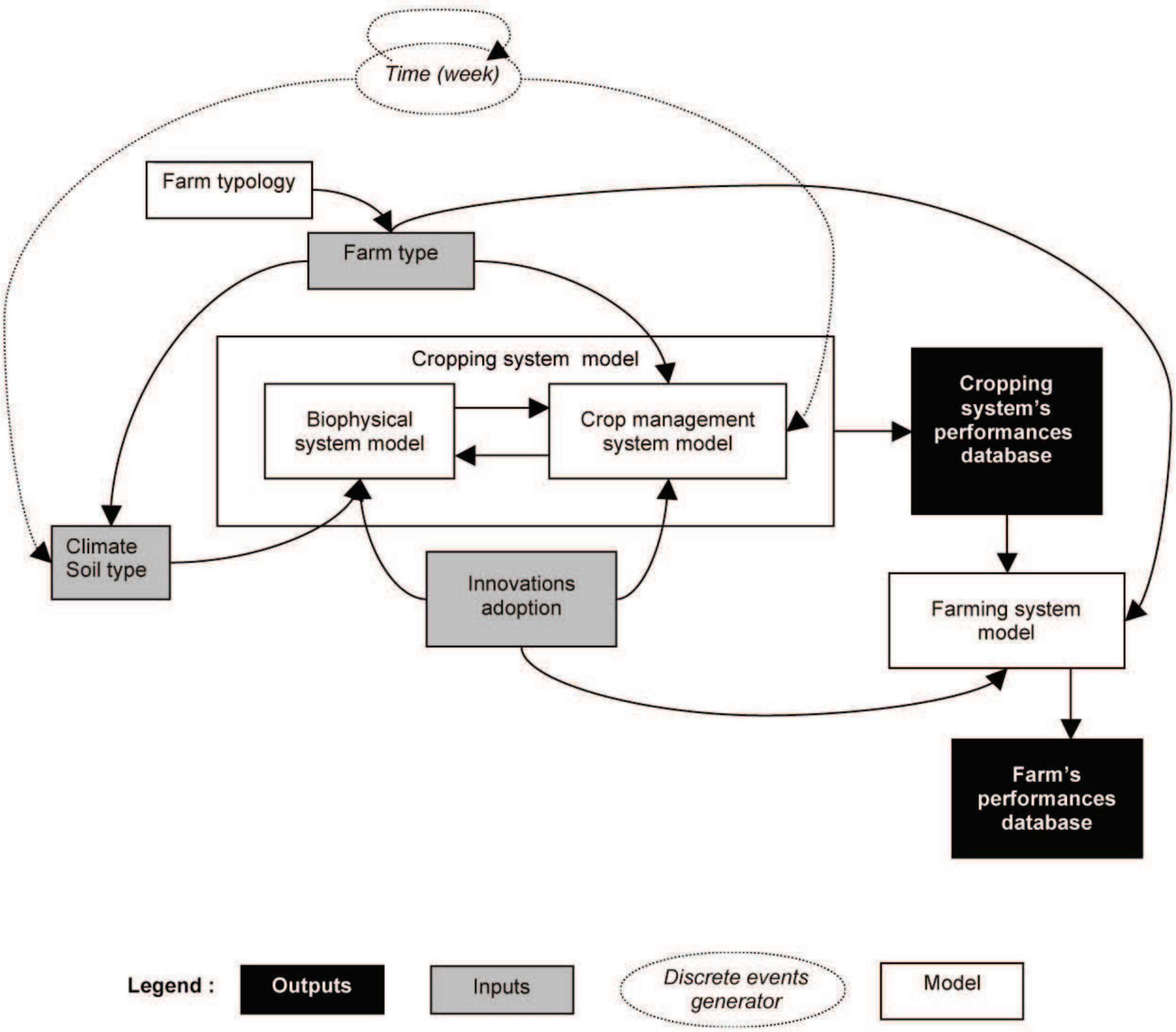
Two workshops were held for the main actors involved in the citrus industry, and included farmers implementing citrus production and specialist researchers in the area of citrus production. A study was undertaken by the researchers with the objective of identifying the types of farming strategies implemented by producers and the constraints they face (Le Bellec et al. 2011). While the goal of the workshop with the stakeholders was aimed at focusing on the design of cropping systems prototypes, the other one for public stakeholders was aimed at establishing objectives for the new cropping system based on an integrated regional perspective. Experiments were performed at the local experimental station to test and adjust the prototypes to performance objectives, and an assessment tool was constructed to evaluate prototypes. It was found that the two main technical constraints that needed to be overcome to improve Guadeloupian citrus cropping systems were: i) the inability to mechanise many fields due to steep slopes and stony soils; and ii) the lack of producer-specific skills regarding the use of chemicals in the management of orchards.

Based on these results, it was collectively agreed that the focus of the redesign process should be on the development of an alternative low-chemical weed control management strategy that would be compatible with the absence of mechanisation on the farms (Le Bellec et al. 2011). Five weed control prototypes were jointly designed as well as two multicriteria assessment tools. Results indicated that farmers involved in the study independently transferred the new technique to their own farms, and as such automatically became pilot farmers. The DISC method created an ongoing dynamic relationship between agricultural and public stakeholders that enabled them find solutions that can be continuously adjusted to stakeholder's, expectations (Le Bellec et al. 2012).

De novo design of banana cropping systems

Blazy et al. (2010) and Archimede et al., (2012) performed an *ex ante* assessment of agroecolgical innovations in banana production in Guadeloupe using modelling. In the case of Blazy et al., (2010), BANAD was used. This is a computer bioeconomic model that jointly simulates bioeconomic and 'technico-economic processes' of resource management at the farm level for assessing several innovative prototypes of environmentally-friendly management systems. The outputs of the BANAD model are dynamic, and based on a weekly time-step. They also include information on the banana production, cash flows, workload and environmental impacts (Figure 9.7). The inputs of the model are the: (i) farm's economic, technical and environmental characteristics; (ii) innovative crop management system parameters; and (iii) policy and market conditions (Blazy et al. 2010).

Figure 9.7: The general structure of BANAD, a bio-economic farm model for the assessment of the impact of innovation adoption

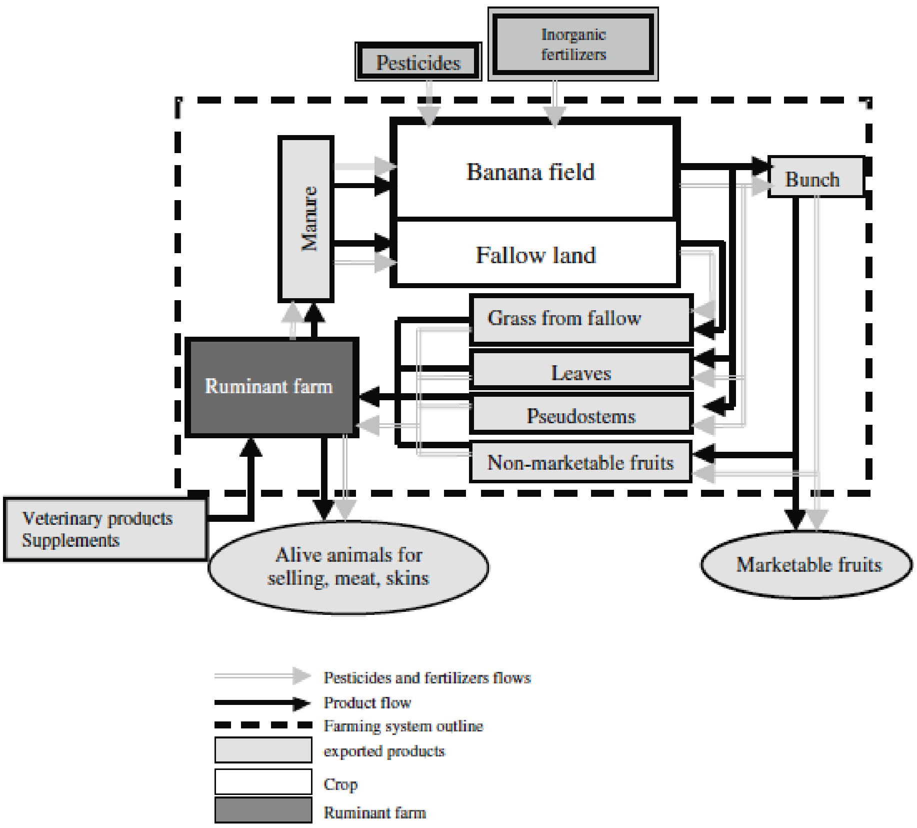


Source: Blazy et al. (2010)

On the other hand, the model employed by Archimede et al. (2012) was a mechanistic model, which was conducted at the farm level. The outputs of this model are also dynamic, but are however based on a yearly time-step and relative to the crop production (total level of biomass of the land fallow and of each compartment of the banana plant including marketable and non-marketable fruits) and animal production (desired stocking rate of animals for the required meat production). The main input data were the total area dedicated to banana production, the percentage of surface to be left in fallow, the specific characteristics of each ruminant species and the average yield and quality of the banana field and its by-products (Figure 9.8).

These two models facilitated the assessment of several agroecological innovations which enabled the reduction or the total avoidance of the use of pesticides in fields. The main innovations tested by Blazy et al. (2010) were the introduction of cultivated rotations to interrupt the cycle of *Radopholus similis* (a nematode), intercropping banana with, firstly *Canavalia ensiformis (*jack bean*)*, a legume cover crop which can limit weed development and provide nitrogen to the soil without increasing the pest population (McIntyre et al. 2001), and secondly, a new hybrid cultivar of banana that has partial resistance to the fungi *Mycosphaerella musicola* and *M. fijiensis*, and which is sufficiently tolerant to the nematode *R. similis* so that fungicide and nematicide application can be avoided (Tixier et al. 2008).

Figure 9.8: Diagrammatic representation of a ICLS based on the integration of banana crops, and small or large ruminants production



Source: Archimede et al., (2012)

An innovative organic banana system consisting of an improved fallow with *Crotalaria juncea*, intercropped with *C. ensiformis*, new hybrid cultivar, and organic fertilisation, with no chemical inputs, was assessed on three different farm types (characterised according to their biophysical and economic parameters). These parameters included the physical state of the land, and the parasite load, climate and soil types, crop rotation, management decision rules and manpower characteristics (cost and efficiency). Using a similar methodology, Archimede et al. (2012) studied the opportunity to transform monoculture banana farms into mixed farming systems with ruminants feeding on banana by-products (leaves, pseudostems and non-marketable fruits), and forage from land left fallow to break the cycle of the nematode *R. similis*.

Five theoretical farm types were established based on the following: presence or absence of the fallow, and the type of ruminants used (i.e. cattle, sheep, or goats). Blazy et al. (2010) found that the impacts of agroecological innovations vary considerably according to: i) the farm type in which the innovation is integrated; ii) the nature of the agroecological innovations; and iii) the criteria considered and the time span of the assessment. The study conducted by Archimede et al. (2012) also revealed that increasing farming system sustainability through alternatives such as using fallow land (rotation) and the integration of ruminant production is feasible from a biotechnical point of view. The methodology employed by these two groups facilitated a rapid assessment of the relevance of innovations under 'real' farm conditions. Such assessment studies would be almost impossible to be made through on-farm trials, and so are more easily accommodated via the utilisation of computer models. This approach would enable the development of policy initiatives to promote the adoption of environmentally-friendly innovations, which for the sake of completeness would still require on-farm validation by stakeholders.

CONCLUSION

Agriculture in the region is extremely diverse and mainly driven by mixed farming systems which include crops and livestock and is practised mainly by rural households. This type of agriculture has nevertheless been excluded for a long time from the political, scientific and technical spheres, giving way to the promotion of export crops. Today, in light of the MEA, the complex diversity and multifunctionality of such agricultural systems is being promoted as an innovative approach to renew productive practices for a sustainable development. Researchers in the region are now able to offer different methodologies to design innovative systems corresponding to the current societal expectations, which can either be gradual (step by step), or sudden (de novo). These have been tested in Guadeloupe in response to certain phytosanitary restrictions faced by the banana and citrus farmers. Other countries in the region can also benefit from these methodologies, which can be adapted to their individual realities. The adoption of these alternative technologies by farmers in our region should therefore be considered a priority.

REFERENCES

Alexandre, G., A. Fanchone, H. Ozier-Lafontaine, J.L. Diman. 2014. Livestock Farming Systems and Agroecology in the Tropics. In *Agroecology and Global Change*, vol. 14, ed. H. Ozier-Lafontaine and M. Lesueur-Jannoyer. Springer: n.p.

Altieri, M.A. 1995. *Agroecology: The Science of Sustainable Agriculture*. Boulder, CO: Westview Press.

Altieri, M.A., and M.V. Toledo. 2011. The Agroecological Revolution in Latin America: Rescuing Nature, Ensuring Food Sovereignty and Empowering Peasants. *Journal Peasant Studies* 38:587–612.

Archimède, H., J.L. Gourdine, A. Fanchone, R. Tournebize, M. Bassien-Capsa and E. Gonzalez-Garcia. 2012. Integrating Banana and Ruminant Production in the French West Indies. *Tropical Animal Health and Production* 44, no. 6:1289–296.

Benyus, J. 1997. *Biomimicry: Innovation Inspired by Nature*. New York: Harper Perennial.

Blazy, JM., P. Tixier, A. Thomas, H. Ozier-Lafontaine, F. Salmon and J. Wery. 2010. BANAD: A Farm Model for Ex Ante Assessment of Agro-Ecological Innovations and Its Application to Banana Farms in Guadeloupe. *Agricultural Systems* 103:221–32.

Boval, M., S. Bellon and G. Alexandre. 2014. Grassland Intensification and Agroecology: – Case Studies in the Caribbean. In *Agroecology and Global Change*, vol. 14, ed. H. Ozier-Lafontaine and M. Lesueur-Jannoyer, Springer: n.p.

Boval, M. and R.M. Dixon. 2012. The Importance of Grasslands for Animal Production and Other Functions: A Review on Management and Methodological Progress in the Tropics. *Animal* 6, no. 5:748–62.

Brown-Uddenberg, R.C., G.W. Garcia, Q.S. Baptiste, T. Counand, O.A. Adogwa and T. Sampson. 2004. *The Agouti [Dasyprocta leporine, D. Aguti]*. Booklet and Producers' Manual. St Augustine, Trinidad: The University of the West Indies.

Cornet, D. 2005. Systèmes de cultures associées a base d'igname et gestion des plantes adventices. Année académique 2004–2005, Faculté des Sciences Agronomiques de Gembloux.

Dawson, T., and R. Fry. 1998. Agriculture in Nature's Image. *Trends Ecol. Evol.* 13:50–51.

Dedieu, B., J. Aubin, G. Duteurtre, G. Alexandre, J. Vayssières, P. Bommel and B. Faye. 2011. Conception et évaluation de systèmes d'élevage durables en régions chaudes à l'échelle de l'exploitation. *INRA Productions Animales* 24:113–28.

Delve, R.J., G. Cadisch, J.C. Tanner, W. Thorpe, P.J. Thorne, K.E. Giller. 2001. Implications of Livestock Feeding Management on Soil Fertility in Smallholder Farming Systems of Sub-Saharan Africa. *Agriculture, Ecosystems and Environment* 84:227–43.

Doré, T., D. Makowski, E. Malezieux, N. Munier-Jolain, M. Tchamitchian and P. Tittonell. 2011. Facing up to the Paradigm of Ecological Intensification in Agronomy: Revisiting Methods, Concepts and Knowledge. *Europ. J. Agronomy* 34, no. 4:197–210. DOI: 10.1016/j.eja.2011.02.006.

Duran-Zuazo, V.H., and C.R. Rodriguez-Pleguezuelo. 2008. Soil-Erosion and Runoff Prevention by Plant Covers: A Review. *Agronomy for Sustainable Development* 28:65–86.

Ecophyto. 2008. http://agriculture.gouv.fr/ecophyto-2018. Accessed June 28, 2011.

Ewel, J. 1999. Natural Systems as Models for the Design of Sustainable Systems of Land Use. *Agroforestry Systems* 45:1–21.

Food and Agriculture Organisation of the United Nations (FAO). 1994. Tropical Soybeans: An Improvement and Production. *Plant Production and Protection Series*, no. 27. Rome: FAO.

Funes-Monzote, F., and M. Monzote. 2001. Integrated Agroecological Systems as a Way Forward for Cuban Agriculture. http://www.lrrd.org/lrrd13/1/fune131.htm. Accessed September 26, 2013.

Funes-Monzote, F.R. 2009. Agricultura con futuro. La alternativa agroecológica para Cuba. Estación Experimental 'Indio Hatuey', Universidad de Matanzas.

Garcia, G.W. 2005. Neotropical Wildlife Conservation, Production, Utilization, Cuisine, Vol. 2. St Augustine, Trinidad and Tobago: GWG Publications.

Gliessman, S.R. 2009. Animals in Agroecosystems. In *Agroecology: The Ecology Of Sustainable Food Systems*. 2nd ed. New York: CRC Press, Taylor & Francis.

González-García, E., J.L. Gourdine, G. Alexandre, H. Archimède and M. Vaarst. 2012. The Complex Nature of Mixed Farming Systems Requires Multidimensional Actions Supported by Integrative Research and Development Efforts. *Animal* 6, no. 5:763–77.

Herrero, M., P.K. Thornton, A.M. Notenbaert, S. Wood, S. Msangi, H.A. Freeman, D. Bossio, J. Dixon, M. Peters, J. Van de Steeg, J. Lynam, P.P. Rao, S. Macmillan, B. Gerard, J. McDermott, C. Sere and M. Rosegrant. 2010. Smart Investments in Sustainable Food Production: Revisiting Mixed Crop-Livestock Systems. *Science* 227(5967): 822–25.

Herrero, M., P.K. Thornton, A. Notenbaert, S. Msangi, S. Wood, R. Kruska, J. Dixon, D. Bossio, J. Van de Steeg, H. Ade Freeman, X. Li, and P. Parthasarathy Rao. 2009. Drivers of Change in Crop-Livestock Systems and Their Potential Impacts on Agro-Ecosystems Services and Human Well-Being to 2030. Nairobi, Kenya: CGIAR Systemwide Livestock Programme, ILRI.

Hipps, N.A., and T.J. Samuelson. 1991. Effects of Long-Term Herbicide Use, Irrigation and Nitrogen Fertiliser on Soil Fertility in an Apple Orchard. *J. Sci. Food Agric.* 55:377–87.

Holling, C.S. 2001. Understanding the Complexity of Economic, Ecological, and Social Systems. *Ecosystems* 4:390–405.

IAASTD. 2008. Executive Summary of the Synthesis Report of the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD). http://www.agassessment.org. Accessed January 23, 2011.

Jolliffe, P.A. 1997. Are Mixed Populations of Plant Species More Productive Than Pure Stands? *Acta Oecologica Scandinavica* (OIKOS) 80, no. 3:595–602.

Khan, Z.R., .W.A. Overholt, A. Hassanali, P. Chiliswa, J. Wandera, F. Muyekho, J.A. Pickett, L.E. Smart and L.J. Wadhams. 1998. An Integrated Management of Cereal Stem Borers and Striga Weed in Maize Based Cropping System in Africa. In *Proceedings of the 6th Eastern and Southern Africa Regional Maize Conference on Maize Production Technology for the Future: Challenges and Opportunities*, CIMMYT (International Maize and Wheat Improvement Centre) and EARO (Ethiopian Agricultural Research).

Kinzig, A.P., P. Ryan, M. Etienne, H. Allison, T. Elmqvist and B.H. Walker. 2006. Resilience and Regime Shifts: Assessing Cascading Effects. *Ecology and Society* 11, no. 1:20.

Lavigne, A., E. Dumbardon-Martial and C. Lavigne. 2012. Poultry for Biological Control of Weeds in Orchards. *Fruit* 67:341–51.

Le Bail, M. 2000. Qualité des produits végétaux et territoire: contribution de l'agronome [Vegetal products quality and territorial development] Oléagineux, Corps gras, Lipides 7:499–503.

Le Bellec, F., P. Cattan, M. Bonin and A. Rajaud. 2011. Building a Typology of Cropping Practices from Comparison to a Common Reference: First Step for a Relevant Cropping System Re-Designing Process-Results for Tropical Citrus Production. *Fruits* 66:143–59.

Le Bellec, F., Rajaud, A., Ozier-Lafontaine, H., Bockstaller, C. and Malezieux, E. 2012. Evidence for Farmers' Active Involvement in Co-Designing Citrus Cropping Systems Using an Improved Participatory Method. *Agronomy for Sustainable Development* 32, no. 3:703–714.

Liang, W. 1998. Farming Systems as an Approach to Agro-Ecological Engineering. *Ecological Engineering* 11:27–35.

Lhoste, P., V. Dollé, J. Rousseau and D. Soltner. 1993. *Zootechnie des régions chaudes. Les systèmes d'élevage.* Paris, Ministère de la Coopération-CIRAD. Manuels et précis d'élevage.

Lyonga, S.N. 1980. Aspects économiques de la culture de l'igname au Cameroun. In *Plantes-racines tropicales: stratégies de recherches pour les années 1980, compte rendu du* *premier symposium triennal sur les plantes-racines de l'ISTRC-AB*, ed. E.R. Terry, K.A. Oduro and F. Caveness, 219–24. Ibadan, Nigeria: IITA.

Ma, S., and S.M. Swinton. 2011. Valuation of Ecosystem Services from Rural Landscapes Using Agricultural Land Prices. *Ecological Economics* 70:1649–59.

Masera, O., Y.M. Astier and S. López-Ridaura. 1999. Sustentabilidad y Manejo de Recursos Naturales. El marco de Evaluación MESMIS. MundiPrensa – GIRA –UNAM, México.

McIntyre, B.D., C.S. Gold, I.N. Kashaija, H. Ssali, G. Night and D.P. Bwamiki. 2001. Effects of Legume Intercrops on Soil-Borne Pests, Biomass, Nutrients and Soil Water in Banana. *Biology and Fertility of Soils* 34:342–48.

Millennium Ecosystem Assessment (MEA). 2005. Ecosystems and Human Well-Being: Synthesis. Washington, DC: Island Press, World Resources Institute.

Meynard, J.M., F. Aggeri, J.B. Coulon, R. Habib and J.P. Tillon. 2006. Conception de systems agricoles innovants [Design of innovative agricultural systems] Report to the INRA National Head.

Meynard, J.M., B. Dedieu and B. Bos. 2012. Re-Design and Co-Design of Farming Systems: An Overview of Methods and Practices. In *Farming Systems Research into the 21st Century: The New Dynamic*, ed. I. Darnhofer, D. Gibbon, and B. Dedieu, 407–431. Dordrecht: Springer.

Midmore, D.J. 1993w. Agronomic Modification of Resource Use and Intercrop Productivity. *Field Crops Research* 34:357–80.

Morris, R.A., and D.P. Garrity. 1993. Resource Capture and Utilization in Intercropping: Water. *Field Crops Research* 34:303–317.

Mundler, P., and L. Rumpus. 2012. The Energy Efficiency of Local Food Systems: A Comparison between Different Modes of Distribution. *Journal of* 37, no. 6:609–615.

Nogueira-Fihlo, S.L.G., D.O. Santos, A. Mendes and S.S. da Cunha Nogueira. 2010. Developping Diets for Collared Peccary from Locally Available Food Resources in Bahia, Brazil. In *Memorias manejo de fauna sylvestre en Amazonia y Latinoamérica*, IXCIMFAUNA, Mayo 10–19, 2010, 458–63. Santa Cruz, Bolivia

Obedoni, B.O., J.K. Mensah and S.O. Isesele Obedoni. 2005. Effects of Intercropping Cowpea {Vigna Unguiculata (Walp} and Tomato (Lycopersicon Esculentum Mill)) on Their Growth, Yield and Monetary Returns. *Indian Journal of Agricultural Research* 39, no. 4: 286–90.

Odurukwe, S.O. 1986. Yam-Maize Intercropping Investigations in Nigeria. *Tropical Agriculture* 63, no. 1:17–21.

Ozier-Lafontaine, H., M. Publicol, J.M., Blazy and C. Melfort. 2011. SIMSERV: Expert System of Assistance to the Selection of Plants of Service for Various Agro-Ecological and Socio-Economic Contexts. Licence CeCILL (http://www.cecill.info/index.en.html). http://toolsforagroecology.antilles.inra.fr/simserv. Accessed January 16, 2014.

Valet, S., and H. Ozier-Lafontaine. 2014. Ecosystemic Services of Multispecific and Multistratified Cropping Systems. In *Agroecology and Global Change*, vol.14, ed. by H. Ozier-Lafontaine and M. Lesueur-Jannoyer. Springer: n.p. (in press).

Parayil, G. 2003. Mapping Technological Trajectories of the Green Revolution and the Gene Revolution from Modernization to Globalization. *Research Policy* 32:971–990.

Preston, T.R. 2009. Sustainable Production of Food, Feed and Fuel from Natural Resources in the Tropics. *Tropical Animal Health and Production* 41:1071–1080.

Preston, T.R., and L. Rodríguez. 2013. Production of Food and Energy from Biomass in an Integrated Farming System, Experiences from the TOSOLY Farm in Colombia. Sustainable Agriculture Reviews (accepted).

Preston, T.R., and L. Rodríguez. 2014. Production of Food and Energy from Biomass in an Integrated Farming System; Experiences from the TOSOLY Farm in Colombia. In *Agroecology and Global Change*, vol.14, ed. H. Ozier-Lafontaine and M. Lesueur-Jannoyer, n.p.: Springer (in press).

Rämert, B., M. Lennartsson and G. Davies. 2002. The Use of Mixed Species Cropping to Manage Pests and Diseases Theory and Practices. In *Proceedings of the COR Conference*, ed. Powel et al., 207–210. Aberystwth: UK Organic Research.

Rey-Novoa, J.M., and F.R. Funes-Monzote. 2013. La familia campesina Rey-Novo una transicion agroecologica. *Agricultures Network* 29, no. 4:12–15.

Risch, S.J. 1983. Intercropping as Cultural Pest Control: Prospects and Limitations. *Environmental Management* 7:9–14.

Root, R.B. 1973. Organization of a Plant-Arthropod Association in Simple and Diverse Habitats – Fauna of Collards (Brassica oleracea). *Ecological Monographs* 4:95–120.

Suárez, J., and G.J. Martín. 2012. La biomasa como fuente renovable de energía en el medio rural: La experiencia del proyecto internacional BIOMAS-CUBA. Estación Experimental 'Indio Hatuey', Matanzas, Cuba.

Susesh, K.K., and R.S.S. Vinaya. 1987. Studies on the Allelopathic Effects of Some Agroforestry Tree Crops. *International Tree Crops Journal* 4:109–115.

Szumigalski, A., and V. Rene. 2005. Weed Suppression and Crop Production in Annual Intercrops. *Weed Science* 53:813–25.

Tixier, P., E. Malézieux, M. Dorel and J. Wery. 2008. SIMBA, a Model for Designing Sustainable Banana-Based Cropping Systems. *Agricultural Systems* 97:139–50.

Trenbath, B.R. 1999. Multispecies Cropping Systems in India. Prediction of Their Productivity, Stability, Resilience and Ecological Sustainability. *Agroforestry Systems* 45:81–107.

Tsubo, M., S. Walker and E. Mukhala. 2001. Comparisons of Radiation Use Efficiency of Mono-/Inter-Cropping Systems with Different Row Orientations. *Field Crops Research* 71:17–29.

Valet, S. 1999. L'aménagement traditionnel des versants et le maintien des cultures associées traditionnelles: cas de l'Ouest-Cameroun. Colloque International 'L' homme et l'Erosion'. IRD-CIRAD. BP 5045, Montpellier, 34032, France. December 12–15,1999. Yaoundé, Cameroun. 17.

Vandermeer, J.H. 1989. *The Ecology of Intercropping*. Cambridge, UK: Cambridge University Press.

Vanloqueren, G., and V. Baret. 2009. How Agricultural Research Systems Shape a Technological Regime That Develops Genetic Engineering but Locks out Agroecological Innovations. *Research Policy* 38:971–83.

Veldkamp, A., A.C. Van Altvorst, R. Eweg, E. Jacobsen, A. Van Kleef, H. Van Latesteijn, S. Mager, H. Mommaas, P.J.A.M. Smeets, L. Spaans and J.C.M. Van Trijp. 2009. Triggering Transitions towards Sustainable Development of the Dutch Agricultural Sector: Transforum's Approach. *Agronomy for Sustainable Development* 29:87–96.

Walker, B., C.S. Holling, S.R. Carpenter and A. Kinzig. 2004. Resilience, Adaptability and Transformability in Social-Ecological Systems. *Ecology and Society* 9, no. 2:5.

Willey, R.W. 1979. Intercropping – Its Importance and Research Neads. Part I: Competition and Yield Advantage; Part II: Agronomy and Research Approaches. *Field crops. Abstr.* 32, no. 1 and 2:1–10.

Young, G.M., C.H.O. Lallo, H. Archimede, G. Legall, G.W. Garcia. 2012. Voluntary Feed Intake and Preference of Locally Available Feeds by the Collared Peccary (Tayassu tajacu/Pecari tajacu) a Neo-Tropical Animal, Farmed in Trinidad, Republic of Trinidad and Tobago. *Livestock Research for Rural Development*, 24, Article #195. http://www.lrrd.org/lrrd24/11/youn24195.htm. Accessed September 12, 2013.

Zhang, W., T.H. Ricketts, C. Kremen, K. Carney and S.M. Swinton. 2007. Ecosystem Services and Dis-Services to Agriculture. *Ecological Economics* 64:253–60.

SUSTAINABLE FOOD PRODUCTION PRACTICES in the Caribbean 2

Edited by
Wayne G. Ganpat and
Wendy-Ann P. Isaac